F ENT COOPERATION TREA .

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE
in its capacity as elected Office

Date of mailing: 01 February 2001 (01.02.01)	
International application No.: PCT/GB00/01601	Applicant's or agent's file reference: PDR/X088390PWO
International filing date: 25 April 2000 (25.04.00)	Priority date: 23 April 1999 (23.04.99)
Applicant: COX, Alan, Michael et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International preliminary Examining Authority on:

16 November 2000 (16.11.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Facsimile No.: (41-22) 740.14.35

Authorized officer:

J. Zahra

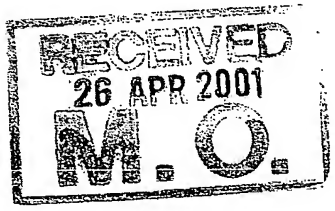
Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

ROBERTS, Peter D
MARKS & CLERK
Sussex House
83-85 Mosley Street
Manchester M2 3LG
GRANDE BRETAGNE



PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT
(PCT Rule 71.1)

Date of mailing *(day/month/year)*	24.04.2001
Applicant's or agent's file reference. PDR/X088390PWO	**IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/01601	25/04/2000	23/04/1999

Applicant
LASER QUANTUM LTD.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Atienza Vivancos, B Tel.+49 89 2399-7891

Form PCT/IPEA/416 (July 1992)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
PDR/X088390PWO		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/01601	25/04/2000	23/04/1999
International Patent Classification (IPC) or national classification and IPC H01S3/083		
Applicant LASER QUANTUM LTD.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
16/11/2000	24.04.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Gnugesser, H Telephone No. +49 89 2399 2526

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/01601

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1-11 as originally filed

Claims, No.:

1-20 as originally filed

Drawings, sheets:

1/1 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

☐ the entire international application.

☒ claims Nos. 20.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. are so unclear that no meaningful opinion could be formed (*specify*):
see separate sheet

☐ the claims; or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

☐ the written form has not been furnished or does not comply with the standard.

☐ the computer readable form has not been furnished or does not comply with the standard.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N) Yes: Claims 1-19

	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-19
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-19
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Re Item III:

See Item VII.3

Re Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

The polarisation selection element comprises at least one mirror spaced away from the gain medium. Therefore, the invention avoids the introduction of an extra polarisation selection element which would cause a decrease of finesse. Consequently, a low loss, high finesse and simple ring laser cavity can be achieved. The available prior art does neither disclose nor indicate the combination of the technical features defined in claim 1. The available prior art discloses monolithic ring laser assemblies or ring laser devices with extra polarisation selective elements (without using a mirror). Consequently, there was no reason for the person skilled in the art to develop the invention from the prior art without exercise of inventive step.
Claims 2 - 19 are dependent claims and are therefore also novel and involve an inventive step (claim 20 see item VII.3 of this international preliminary examination report).

Re Item VII

Certain defects in the international application

1. The independent claim is not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the closest prior art being placed in the preamble (Rule 6.3(b)(I) PCT) and with the remaining features being included in the characterising

part (Rule 6.3(b)(ii) PCT).

2. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

3. Claim 20 contains a reference to the drawing. According to Rule 6.2(a) PCT, claims should not contain such references except where absolutely necessary, which is not the case here. Consequently, claim 20 should have been deleted.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 February 2001 (01.02.2001)

PCT

(10) International Publication Number
WO 01/08274 A1

(51) International Patent Classification[7]: H01S 3/083

(21) International Application Number: PCT/GB00/01601

(22) International Filing Date: 25 April 2000 (25.04.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9909252.0 23 April 1999 (23.04.1999) GB

(71) Applicant *(for all designated States except US)*: **LASER QUANTUM LTD** [GB/GB]; Enterprise House, Manchester Science Park, Lloyd Street North, Manchester M15 6SE (GB).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **COX, Alan, Michael** [GB/GB]; 2 Marley Road, Levenshulme, Manchester M19 2TA (GB). **GLOSTER, Lawrence, Anthony, William** [GB/GB]; 7 Guywood Cottages, Guywood Lane, Romiley SK6 4AT (GB). **LANE, Steve, Haydn** [GB/GB]; 14 Hatherley Road, Withington, Manchester M20 4RN (GB).

(74) Agent: **ROBERTS, Peter, David**; Marks & Clerk, Sussex House, 83-85 Mosley Street, Manchester M2 3LG (GB).

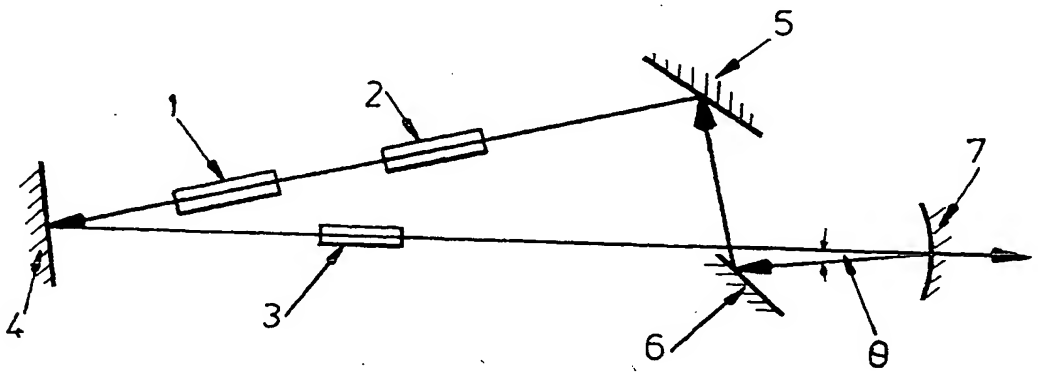
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LASER CAVITY



(57) Abstract: A non-monolithic ring laser cavity comprising: (a) a gain medium (1); (b) a first polarisation rotation element arranged to rotate the polarisation of light propagating in the cavity with a predetermined handedness irrespective of the direction of propagation of the light; (c) a second polarisation rotation element (7) arranged to rotate the polarisation of light propagating in the cavity with a handedness which is dependent upon the direction of propagation of the light; (d) a polarisation selection element (5, 6) arranged to cause loss to light propagating in the cavity, the loss being determined by the polarisation of light incident upon the polarisation selection element; wherein the polarisation selection element comprises at least one mirror spaced away from the gain medium (1) and arranged to reflect light at an angle displaced from the normal such that the reflectivity of the at least one mirror is sufficiently polarisation dependent that the laser oscillates uni-directionally.

WO 01/08274 A1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/01601

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01S3/083

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 578 793 A (BYER ROBERT L ET AL) 25 March 1986 (1986-03-25) column 4, line 22 -column 6, line 15; figures 1-3A	1,2,5,17
A	TRUTNA W R ET AL: "TWOOPIECE, PIEZOELECTRICALLY TUNED, SINGLE-MODE ND:YAG RING LASER" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 15, no. 7, 1 April 1990 (1990-04-01), pages 369-371, XP000126552 ISSN: 0146-9592 the whole document	1

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 June 2000	30/06/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Gnugesser, H

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/01601

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 482 249 A (SMITH JR IRL W ET AL) 13 November 1984 (1984-11-13) column 2, line 45 -column 3, line 30 column 5, line 21 -column 5, line 38 column 6, line 27 -column 6, line 46 column 8, line 21 -column 9, line 35; figures 1,4	1

1

INTERNATIONAL SEARCH REPORT

Intern[illegible]al Application No
PCT/[illegible]B 00/01601

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4578793 A	25-03-1986	JP 1665113 C	19-05-1992
		JP 3028076 B	17-04-1991
		JP 61093686 A	12-05-1986
US 4482249 A	13-11-1984	US 4110045 A	29-08-1978

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
PDR/X088390PWO		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/01601	25/04/2000	23/04/1999
International Patent Classification (IPC) or national classification and IPC H01S3/083		
Applicant LASER QUANTUM LTD.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
16/11/2000	24.04.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Gnugesser, H Telephone No. +49 89 2399 2526

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/01601

I. Basis f th r p rt

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1-11 as originally filed

Claims, No.:

1-20 as originally filed

Drawings, sheets:

1/1 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

   ☐ the entire international application.

   ☒ claims Nos. 20.

because:

   ☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

   ☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. are so unclear that no meaningful opinion could be formed (*specify*):
   see separate sheet

   ☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

   ☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

   ☐ the written form has not been furnished or does not comply with the standard.

   ☐ the computer readable form has not been furnished or does not comply with the standard.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and xplanations supporting such statement

1. Statement

   Novelty (N) Yes: Claims 1-19

	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-19
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-19
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
s e separate sheet

R Item III:

See Item VII.3

Re Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

The polarisation selection element comprises at least one mirror spaced away from the gain medium. Therefore, the invention avoids the introduction of an extra polarisation selection element which would cause a decrease of finesse. Consequently, a low loss, high finesse and simple ring laser cavity can be achieved. The available prior art does neither disclose nor indicate the combination of the technical features defined in claim 1. The available prior art discloses monolithic ring laser assemblies or ring laser devices with extra polarisation selective elements (without using a mirror). Consequently, there was no reason for the person skilled in the art to develop the invention from the prior art without exercise of inventive step.
Claims 2 - 19 are dependent claims and are therefore also novel and involve an inventive step (claim 20 see item VII.3 of this international preliminary examination report).

Re Item VII

Certain defects in the international application

1. The independent claim is not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the closest prior art being placed in the preamble (Rule 6.3(b)(I) PCT) and with the remaining features being included in the characterising

part (Rule 6.3(b)(ii) PCT).

2. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

3. Claim 20 contains a reference to the drawing. According to Rule 6.2(a) PCT, claims should not contain such references except where absolutely necessary, which is not the case here. Consequently, claim 20 should have been deleted.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
PDR/X088390PWO		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB 00/ 01601	25/04/2000	23/04/1999
Applicant		
LASER QUANTUM LTD.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [ ] the text is approved as submitted by the applicant.

   [X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

   [ ] as suggested by the applicant.

   [X] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

line 2 : after "medium", insert "(1)"
line 6 : after "rotation element", insert "(7)"
line 9 : after "selection element", insert "(5, 6)"
line 13 : after "gain medium", insert "(1)"

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/01601

A. CLASSIFICATION OF SUBJECT MATTER
IPC·7 H01S3/083

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 578 793 A (BYER ROBERT L ET AL) 25 March 1986 (1986-03-25) column 4, line 22 -column 6, line 15; figures 1-3A ---	1,2,5,17
A	TRUTNA W R ET AL: "TWOOPIECE, PIEZOELECTRICALLY TUNED, SINGLE-MODE ND:YAG RING LASER" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 15, no. 7, 1 April 1990 (1990-04-01), pages 369-371, XP000126552 ISSN: 0146-9592 the whole document --- -/--	1

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 June 2000	30/06/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gnugesser, H

1

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 482 249 A (SMITH JR IRL W ET AL) 13 November 1984 (1984-11-13) column 2, line 45 -column 3, line 30 column 5, line 21 -column 5, line 38 column 6, line 27 -column 6, line 46 column 8, line 21 -column 9, line 35; figures 1,4	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/01601

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4578793 A	25-03-1986	JP 1665113 C	19-05-1992
		JP 3028076 B	17-04-1991
		JP 61093686 A	12-05-1986
US 4482249 A	13-11-1984	US 4110045 A	29-08-1978

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 February 2001 (01.02.2001)

PCT

(10) International Publication Number
WO 01/08274 A1

(51) International Patent Classification[7]: H01S 3/083

(21) International Application Number: PCT/GB00/01601

(22) International Filing Date: 25 April 2000 (25.04.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9909252.0 23 April 1999 (23.04.1999) GB

(71) Applicant *(for all designated States except US)*: **LASER QUANTUM LTD** [GB/GB]; Enterprise House, Manchester Science Park, Lloyd Street North, Manchester M15 6SE (GB).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **COX, Alan, Michael** [GB/GB]; 2 Marley Road, Levenshulme, Manchester M19 2TA (GB). **GLOSTER, Lawrence, Anthony, William** [GB/GB]; 7 Guywood Cottages, Guywood Lane, Romiley SK6 4AT (GB). **LANE, Steve, Haydn** [GB/GB]; 14 Hatherley Road, Withington, Manchester M20 4RN (GB).

(74) Agent: **ROBERTS, Peter, David**; Marks & Clerk, Sussex House, 83-85 Mosley Street, Manchester M2 3LG (GB).

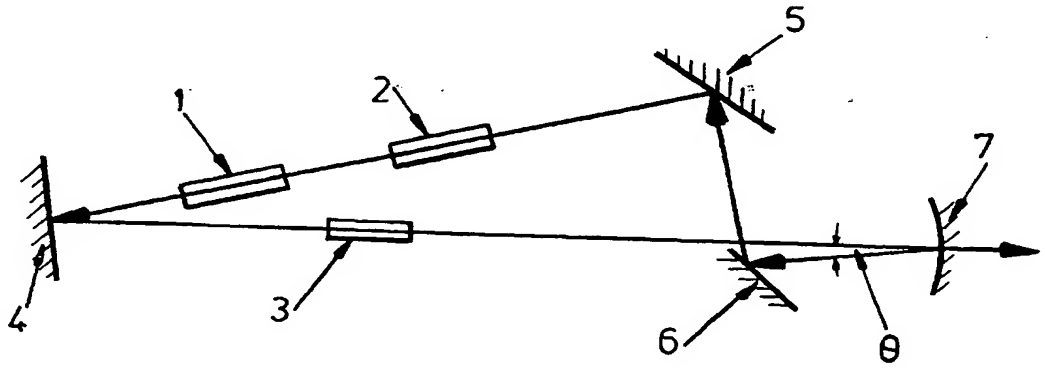
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LASER CAVITY



(57) Abstract: A non-monolithic ring laser cavity comprising: (a) a gain medium (1); (b) a first polarisation rotation element arranged to rotate the polarisation of light propagating in the cavity with a predetermined handedness irrespective of the direction of propagation of the light; (c) a second polarisation rotation element (7) arranged to rotate the polarisation of light propagating in the cavity with a handedness which is dependent upon the direction of propagation of the light; (d) a polarisation selection element (5, 6) arranged to cause loss to light propagating in the cavity, the loss being determined by the polarisation of light incident upon the polarisation selection element; wherein the polarisation selection element comprises at least one mirror spaced away from the gain medium (1) and arranged to reflect light at an angle displaced from the normal such that the reflectivity of the at least one mirror is sufficiently polarisation dependent that the laser oscillates uni-directionally.

WO 01/08274 A1

Laser Cavity

The present invention relates to a laser cavity, and in particular to a ring laser cavity.

Laser cavities configured as rings have been widely used to eliminate a problem known as spatial hole burning. Spatial hole burning occurs in laser cavities which allow light to propagate in opposing directions within a gain medium, for example in a linear laser cavity. Light in such a laser cavity forms a standing wave, which selectively depletes the gain medium according to the localised intensity distribution of this standing wave (spatial hole burning). The effect of the spatial hole burning is to make several longitudinal modes of the laser cavity oscillate simultaneously in a homogeneously broadened laser (which may otherwise exhibit single longitudinal mode behaviour), thereby compromising the spectral purity of the laser. This multimode behaviour can cause instabilities in laser systems that are intra-cavity doubled (T. Baer, 'Large-amplitude fluctuations due to longitudinal mode coupling in diode-pumped intracavity-doubled Nd:YAG lasers,' J. Opt. Soc. Am. B 3, 1175 (1986)).

In a ring laser, light generated by stimulated emission in the gain medium is made to propagate in one direction only around the ring, thereby preventing the formation of standing waves and avoiding the resulting spatial hole burning in the gain medium. Since there is no spatial hole burning in the gain medium, the laser may oscillate in a single longitudinal mode (provided that the gain medium is predominantly homogeneously broadened). The single longitudinal mode in an intra-cavity doubled, uni-directional ring laser is considerably more stable than the multiple modes seen in a conventional intra-cavity doubled laser cavity, and is significantly less sensitive to environmental changes, such as temperature fluctuations.

If light is allowed to propagate in both directions in a ring cavity, spatial hole burning can occur and the main advantages of a ring laser cavity over a linear laser cavity are lost.

In order to allow the light to propagate in only one direction around a ring laser cavity, the loss suffered by light propagating in an unwanted direction must be made greater than the loss suffered by light propagating in the preferred direction. Provided that the difference between the two losses is sufficient, the laser cavity will oscillate in the preferred direction only.

In order to impose differing losses on light propagating in opposite directions around a ring laser cavity, it is necessary to combine three effects. These are as follows :

1) Rotation of the polarisation of the light with the same handedness (with respect to its direction of travel) whichever direction the light is propagating around the ring laser cavity (for example using a quartz plate). This is known as reciprocal rotation.
2) Right handed rotation of the polarisation of light propagating in a first preferred direction and left handed rotation of the polarisation of light propagating in an unwanted, opposite direction around the ring laser cavity (or vice-versa). This can be achieved using a Faraday rotator . This is known as non-reciprocal rotation.
3) Selective transmission of light having polarisation in a predetermined plane (for example using a Brewster-angled plate). This effect is referred to as polarisation selectivity.

In a system incorporating the above three effects, a beam propagating in the preferred direction will have its polarisation rotated away from and then back towards its initial polarisation orientation, and will be transmitted with relatively low loss by the polarisation selectivity. In contrast to this, a beam propagating in the unwanted direction will have its polarisation rotated in one direction and then further rotated in the same direction (away from the initial polarisation orientation), and will suffer a greater loss due to the polarisation selectivity.

When designing laser cavities for efficient intra-cavity doubling it is necessary to achieve a high cavity finesse to keep the loss suffered by an oscillating mode in the cavity to a minimum, since any increase of the loss will cause a corresponding decrease of finesse and, therefore, efficiency.

It is an object of the present invention to provide a ring laser cavity having a low loss.

According to the invention there is provided a non-monolithic ring laser cavity comprising:

a. a gain medium;

b. a first polarisation rotation element arranged to rotate the polarisation of light propagating in the cavity with a predetermined handedness irrespective of the direction of propagation of the light;

c. a second polarisation rotation element arranged to rotate the polarisation of light propagating in the cavity with a handedness which is dependent upon the direction of propagation of the light;

d. a polarisation selection element arranged to cause loss to light propagating in the cavity, the loss being determined by the polarisation of light incident upon the polarisation selection element;

wherein the polarisation selection element comprises at least one mirror spaced away from the gain medium and arranged to reflect light at an angle displaced from the normal such that the reflectivity of the at least one mirror is sufficiently polarisation dependent that the laser oscillates uni-directionally.

When light is reflected from a mirror at an angle displaced from the normal, the mirror may have a greater reflectivity for s-polarised light than for p-polarised light. At large enough angles of incidence, the reflectivity of a mirror will become sufficiently polarisation dependent that it can act as the required polarisation selection element such that a ring laser incorporating the mirror is forced to oscillate uni-directionally (two or more mirrors arranged to reflect at lesser angles may provide an equivalent cumulative effect). The term 'sufficiently polarisation dependent' is

intended to mean that uni-directional oscillation is achieved without introducing an extra polarisation selection element into the cavity, for example a Brewster plate or a Brewster angled window at one or both ends of a gain medium. The term 'sufficiently polarisation dependent' is not intended to exclude a ring laser cavity wherein the polarisation dependent reflection of the at least one mirror is supplemented with polarisation selectivity provided by a natural polarisation preference of a gain medium in the ring laser cavity.

The invention allows the construction of a low loss, high finesse ring laser cavity, since the introduction of an extra polarisation selection element is avoided. High finesse is particularly important if the laser cavity includes a frequency-doubling element. A further advantage of the invention is that it is possible to achieve a small reflection angle on an output coupling mirror (which is often curved). This small reflection angle is beneficial because the astigmatic effects caused by the output mirror are kept to a minimum.

The ring laser cavity preferably comprises three or more mirrors, and most preferably comprises four mirrors (although more mirrors may be used). Where four or more mirrors are used, the first polarisation rotation element may comprise one mirror of the cavity located such that the point of reflection of the beam is out of the plane defined by the points of reflection of three of the other mirrors. This is known as a non-planar ring oscillator (NPRO).

Preferably, the second polarisation rotation element comprises a Faraday rotator.

Preferably, the angle of reflection of the at least one angled mirror is greater than 25 degrees. The angle is measured relative to the normal from the mirror. The angle is chosen to be greater than 25 degrees in order to provide the polarisation selectivity required by the invention.

Preferably, the angle of reflection of the at least one angled mirror is between 40 degrees and 55 degrees. High reflectivity dielectric mirrors configured to reflect at approximately 45 degrees are available commercially 'off the shelf', and these may be used to reflect with good efficiency from 40 degrees to 55 degrees.

The angle of reflection of the at least one angled mirror may be greater than 55 degrees.

The at least one angled mirror may comprise two mirrors arranged to reflect light at an angle displaced from the normal such that the cumulative reflectivity of the two mirrors is sufficiently polarisation dependent that the laser oscillates uni-directionally.

The polarisation selection element may comprise two consecutively reflecting angled mirrors.

Preferably, one of the mirrors is concave, and is arranged to reflect light at less than 8 degrees from the normal. More preferably, the concave mirror is arranged to reflect light at less than 4 degrees from the normal. This reduces the astigmatic effect of the concave mirror (which is commonly an output coupler).

Suitably, the cavity further includes a frequency doubling element arranged to double the frequency of light generated by the laser gain medium.

Suitably, the frequency doubling element comprises a crystal of Potassium Titanyl Phosphate (KTP). Alternatively, the frequency doubling element comprises a Potassium Niobate ($KNbO_3$) crystal. Alternatively, the frequency doubling element comprises a crystal of Lithium Triborate (LBO).

Preferably, the gain medium is excited by light generated by one or more semiconductor devices. A semiconductor device may for example be a laser diode.

Suitably, the light generated by the one or more semiconductor devices is directed into the gain medium such that it has an absorption profile in the gain medium which substantially corresponds to the profile of the laser mode in the gain medium.

Alternatively, the one or more semiconductor devices are arranged to direct light into the gain medium by illumination from the sides of the gain medium.

Suitably, the gain medium comprises a crystal of Yttrium Aluminium Garnet (YAG) doped with a suitable element. The doping element may be for example Neodymium. The gain medium may alternatively be Vanadate (YVO_4) doped with a suitable element, for example Neodymium. Alternatively, the gain medium may be a material commonly known as Lanthanum Scandium Borate (LSB), doped with a suitable element, for example Neodymium.

The invention is not intended to include monolithic laser cavities. A monolithic laser cavity is a laser cavity in which an entire optical cavity is formed from a single crystal or glass element, or crystals or glass elements optically bonded together to form a laser cavity, such that intra-cavity laser light travels only through the crystal or glass elements or elements. Monolithic lasers are not suited to the generation of frequency doubled light using an intra-cavity frequency doubling element.

Specific embodiments of the invention will now be described by way of example only, with reference to the accompanying drawing which shows schematically a laser cavity according to the invention.

The drawing shows a first embodiment of the invention; a laser cavity comprising a gain medium 1, a Faraday rotator 2, and a non-linear crystal 3, all located in a cavity defined by four mirrors 4-7. In the illustrated embodiment the gain medium is a rod of Nd:YAG, which emits light at 1064nm. The non-linear crystal 3 comprises a rod of Potassium Titanyl Phosphate (KTP) which is arranged to

frequency-double light in the cavity from 1064nm to 532nm. Mirror 4 is designed to be highly reflecting at the fundamental wavelength (in this case 1064 nm). Mirrors 5 and 6 are highly reflecting at 1064 nm for a reflection angle of typically 45 degrees from the normal. Mirror 7 is highly reflecting at 1064 nm and is highly transmissive at 532 nm. In an alternative embodiment of the invention the cavity may be constructed without the non-linear crystal present. In this case the mirror 7 is coated to partially transmit 1064 nm light, to allow a proportion of the 1064 nm light to be output from the cavity.

The Nd:YAG rod 1 is pumped optically using, for example, a diode laser (not shown) with sufficient intensity that laser oscillation of light at 1064nm occurs in the cavity. The optical pump light provided by the diode laser is preferably arranged such that an absorption profile of the pump light within the Nd:YAG rod 1 is substantially matched with the profile of the laser mode in the Nd:YAG rod 1. The diode laser may alternatively be arranged to direct light into the gain medium by illumination from the sides of the gain medium (this arrangement is not preferred because it is less efficient).

A portion of the 1064nm light (typically <0.5% per pass) is frequency doubled by the KTP rod 3, and this frequency-doubled light is emitted as a coherent beam from the output coupler 7.

At least one mirror, preferably the output coupler 7, is concave to maintain a stable oscillating mode of the laser cavity. The mirror 4 facing the output coupler 7 may also be concave.

If no directionally selective elements are included in the cavity, then oscillating modes will be able to propagate in opposite directions around the cavity, and this will lead to spatial hole burning in the gain medium 1. In order to make the light propagate in only one direction around the laser cavity, the loss suffered by light propagating in an unwanted direction is made greater than the loss suffered by light propagating in the preferred direction. The required directional selectivity is provided

by a combination of the polarisation rotation caused by the Faraday rotator 2, polarisation rotation caused by locating one of the mirrors outside of a plane defined by the other three, and polarisation selectivity obtained by making two of the mirrors 5,6 reflect light at approximately 45 degrees to the normal.

The Faraday rotator 2 causes a right-hand polarisation rotation of light propagating in a preferred direction in the cavity, and causes a left-hand polarisation rotation of light propagating in an unwanted, opposite, direction. The out-of-plane nature of the cavity causes a polarisation rotation of the light which is always left-handed regardless of the direction of propagation of the light around the ring. Thus, the polarisation of light propagating in the preferred direction suffers relatively little net polarisation rotation from the combined effect of the Faraday rotator 2 and the out-of-plane nature of the cavity, whereas the polarisation of light propagating in the unwanted, opposite, direction suffers a greater net rotation.

The reflectivity of the mirrors 5,6 arranged to reflect light at 45 degrees (hereafter referred to as the angled mirrors) is typically greater for s-polarised light than it is for p-polarised light. Light which propagates around the cavity in the preferred direction, provided that it is initially s-polarised, will be relatively unaffected by the combined effect of the Faraday rotator 2 and the out-of-plane nature of the cavity, and will be reflected with high reflectivity from the mirrors 5,6. Light which propagates around the cavity in the unwanted direction, if initially s-polarised, will be rotated by the combined effects of the Faraday rotator 2 and the out-of-plane nature of the cavity, such that it has a degree of p-polarisation, and will be reflected with a lesser reflectivity from the angled mirrors 5,6.

The angled mirrors are dielectric coated mirrors, and can typically reflect s-polarised light with a loss of <0.05%, and p-polarised light with a loss of typically 1-3%. This polarisation selectivity is arranged to be sufficient to cause enough loss to light propagating in the unwanted direction that oscillation of light propagating in that direction in the cavity is suppressed. Spatial hole burning is thus suppressed and the

cavity can oscillate in a single longitudinal mode as the gain medium is predominantly homogeneously broadened.

The use of the two angled mirrors 5,6 is advantageous because it does not introduce significant loss into the cavity. This is particularly important when the cavity includes a frequency-doubling crystal (as shown in the drawing), because the efficiency of the frequency doubling process relies upon a high cavity finesse, which in turn is dependent upon the cavity having a low loss. In a high finesse laser cavity, the intensity of light inside the cavity can be so high that loss caused by the introduction of a polarisation selection element is unsatisfactory. Even an additional loss of 0.1%, for example due to the introduction of a Brewster plate into the cavity, may cause unacceptable deterioration of the finesse of the cavity. Ideally, most of the loss in the cavity should occur due to frequency conversion in the KTP rod 3, leading to light being usefully lost through the output coupler 7. This conversion is typically <0.5% efficient.

The angled mirrors 5,6 are manufactured to provide high reflectivity of light at around 45 degrees incidence relative to the normals of the mirrors. Mirrors of this type are readily available, and are relatively inexpensive. However, mirrors arranged to reflect light at angles other than 45 degrees may be used. In general, the reflectivity with regard to s-polarised light is easily made high at angles of incidence greater than 45 degrees, but the reflectivity of the p-polarised light is usually reduced, thereby enhancing the polarisation selectivity. In contrast to this, the polarisation selectivity is usually small for mirrors reflecting light at less than 20 degrees to the normal. At zero degrees, there is typically no appreciable selectivity at all.

Where the polarisation selectivity is enhanced, the degree of polarisation rotation induced by the Faraday rotator 2 may be reduced without compromising the uni-directional operation of the laser. This is advantageous because it allows a shorter, and therefore cheaper, Faraday rotator crystal to be used. Similarly, when the polarisation selectivity is enhanced, the degree of polarisation rotation induced by the out-of-plane cavity may be reduced.

Ideally, light propagating in the preferred direction is almost exclusively s-polarised when it is reflected by both of the angled mirrors 5 and 6.

Often, as the angle of reflection from the normal increases, it is possible to achieve lower loss for an s-polarised beam reflecting off an appropriately designed mirror. The invention is therefore advantageous because the angled mirrors 5,6 allow the reduction of losses suffered by s-polarised light.

The Faraday rotator 2 consists of a strong magnet and a material with a large Verdet constant. This constant links the polarisation rotation to the magnetic field applied to the material and the length of the crystal. Typically, the polarisation rotation introduced by the Faraday rotator 2 is a few degrees (less than 10 degrees), as is the corresponding rotation caused by the out of plane nature of the cavity. Certain gain media can also be used as Faraday rotators e.g. Nd:YAG.

The frequency doubling crystal will introduce a non-linear coupling loss of typically 0.5 % in the preferred direction (by conversion from 1064 nm to 532 nm); a loss which is intensity dependent and is not present for the opposite, unwanted propagation direction. The differential loss due to the polarisation control described earlier must be greater than this non-linear loss in order to ensure that the laser robustly oscillates only in the correct direction around the ring.

A further advantage of the cavity configuration shown in the drawing is that a small reflectance angle ϑ is subtended at the curved output coupler 7, as compared to the angle subtended in conventional ring laser cavities. The reduction of the reflectance angle ϑ reduces the astigmatic effect of the curved mirror 7.

It will be appreciated that the direction of polarisation rotation induced by the Faraday rotator 2 may be reversed by reversing the direction of the applied magnetic field, and that the preferred direction of propagation in the ring laser cavity may be correspondingly reversed.

The gain medium (in this example Nd:YAG) may be located between the frequency doubling crystal 3 and the mirror 4.

It will be understood that the invention is not limited to ring laser cavities having a Nd:YAG gain medium, but may be applied to a ring laser cavity having any other suitable gain medium. The gain medium may be Vanadate (YVO_4) doped with a suitable element, for example Neodymium. Alternatively, the gain medium may be a material commonly known as LSB, doped with a suitable element, for example Neodymium.

Although the described embodiment of the invention includes a KTP frequency doubling element, any other suitable frequency doubling element may be used, for example a Potassium Niobate ($KNbO_3$) crystal, or a crystal of the material commonly known as LBO.

Although the described embodiment of the invention includes a diode laser operating as an optical pump, the gain medium may be excited by any suitable means.

Claims

1. A non-monolithic ring laser cavity comprising:

a. a gain medium;

b. a first polarisation rotation element arranged to rotate the polarisation of light propagating in the cavity with a predetermined handedness irrespective of the direction of propagation of the light;

c. a second polarisation rotation element arranged to rotate the polarisation of light propagating in the cavity with a handedness which is dependent upon the direction of propagation of the light;

d. a polarisation selection element arranged to cause loss to light propagating in the cavity, the loss being determined by the polarisation of light incident upon the polarisation selection element;

wherein the polarisation selection element comprises at least one mirror spaced away from the gain medium and arranged to reflect light at an angle displaced from the normal such that the reflectivity of the at least one mirror is sufficiently polarisation dependent that the laser oscillates uni-directionally.

2. A ring laser cavity according to claim 1, wherein the cavity comprises three or more mirrors.

3. A ring laser cavity according to claim 1 or 2, wherein the cavity comprises four or more mirrors.

4. A ring laser cavity according to claim 3, wherein the first polarisation rotation element comprises one mirror of the cavity located such that the point of reflection of the beam is out of the plane defined by the points of reflection of three of the other mirrors.

5. A ring laser cavity according to any of claims 1 to 4, wherein the second polarisation rotation element comprises a Faraday rotator.

6. A ring laser cavity according to any preceding claim, wherein the angle of reflection of the at least one angled mirror is greater than 25 degrees.

7. A ring laser cavity according to claim 6, wherein the angle of reflection of the at least one angled mirror is between 40 and 55 degrees.

8. A ring laser cavity according to claim 7, wherein the angle of reflection of the at least one angled mirror is greater than 55 degrees.

9. A ring laser cavity according to any preceding claim, wherein the at least one angled mirror comprises two mirrors arranged to reflect light at an angle displaced from the normal such that the cumulative reflectivity of the two mirrors is sufficiently polarisation dependent that the laser oscillates uni-directionally.

10. A ring laser cavity according to any preceding claim, wherein one of the mirrors is concave, and is arranged to reflect light at less than 8 degrees from the normal.

11. A ring laser cavity according to claim 10, wherein the concave mirror is arranged to reflect light at less than 4 degrees from the normal.

12. A ring laser cavity according to any preceding claim, wherein the cavity further includes a frequency doubling element arranged to double the frequency of light generated by the laser gain medium.

13. A ring laser cavity according to claim 12, wherein the frequency doubling element comprises a crystal of Potassium Titanyl Phosphate.

14. A ring laser cavity according to any preceding claim, wherein the gain medium is excited by light generated by one or more semiconductor devices.

15. A ring laser cavity according to claim 14, wherein the light generated by the one or more semiconductor devices is directed into the gain medium such that it has an absorption profile in the gain medium which substantially corresponds to the profile of the laser mode in the gain medium.

16. A ring laser cavity according to claim 14, wherein the one or more semiconductor devices is arranged to direct light into the gain medium by illumination from the sides of the gain medium.

17. A ring laser cavity according to any preceding claim, wherein the gain medium comprises a crystal of Yttrium Aluminium Garnet (YAG) doped with a suitable element.

18. A ring laser cavity according to any preceding claim, wherein at least two mirrors are spaced away from the gain medium.

19. A ring laser cavity according to claim 18, wherein at least three mirrors are spaced away from the gain medium.

20. A ring laser cavity substantially as hereinbefore described with reference to the accompanying drawing.

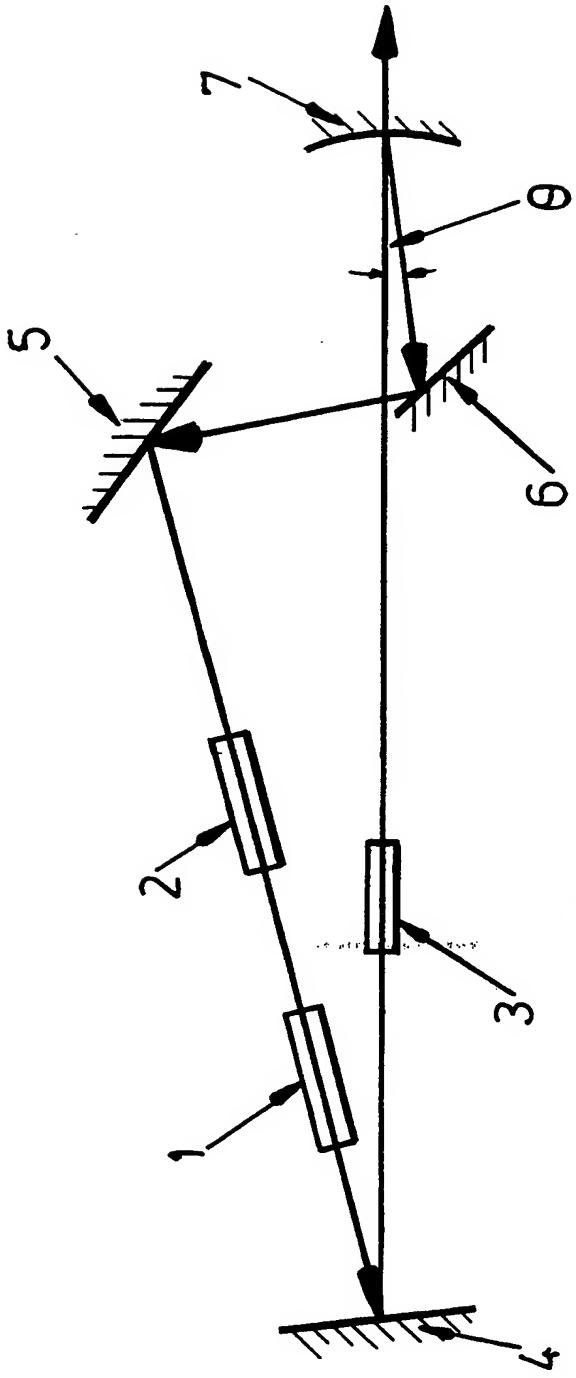


FIG. 1

INTERNATIONAL SEARCH REPORT

Interna[redacted] Application No
PCT/GB 00/01601

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01S3/083

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 578 793 A (BYER ROBERT L ET AL) 25 March 1986 (1986-03-25) column 4, line 22 -column 6, line 15; figures 1-3A	1,2,5,17
A	TRUTNA W R ET AL: "TWOOPIECE, PIEZOELECTRICALLY TUNED, SINGLE-MODE ND:YAG RING LASER" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 15, no. 7, 1 April 1990 (1990-04-01), pages 369-371, XP000126552 ISSN: 0146-9592 the whole document	1

-/--

[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 June 2000	30/06/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Gnugesser, H

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/01601

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 482 249 A (SMITH JR IRL W ET AL) 13 November 1984 (1984-11-13) column 2, line 45 -column 3, line 30 column 5, line 21 -column 5, line 38 column 6, line 27 -column 6, line 46 column 8, line 21 -column 9, line 35; figures 1,4	1

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/01601

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4578793 A	25-03-1986	JP 1665113 C	19-05-1992
		JP 3028076 B	17-04-1991
		JP 61093686 A	12-05-1986
US 4482249 A	13-11-1984	US 4110045 A	29-08-1978